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WELDING OF TITANIUM: AN ANNOTATED BIBLIOGRAPHY

SPECIAL BIBLIOGRAPHY
SB-62-40

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WELDING OF TITANIUM: AN ANNOTATED BIBLIOGRAPHY

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OCTOBER 1962

Lockheed

MISSILES & SPACE COMPANY

A GROUP DIVISION OF LOCKHEED AIRCRAFT CORPORATION

SUNNYVALE, CALIFORNIA

ABSTRACT

Titanium is one of the more difficult metals to fabricate. The scope of this search deals with the area of welding. Information is included on arc welding, brazing, electron beam welding, electroslag welding, diffusion bonding, fusion welding, friction welding, resistance welding, Tig welding, and ultrasonic welding.

The references are arranged alphabetically by author. References which do not list an author are arranged according to the key word in the title.

The period of coverage dates from January 1958 through March 1962.
Search completed July 1962. 76 references.

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WELDING OF TITANIUM: AN ANNOTATED BIBLIOGRAPHY

1. Arc welding titanium. Imperial Chemical Industries, Ltd. British Patent 803,166 Abstracted in: METALWORKING PRODUCTION v. 102, n. 51, p. 2243, December 19, 1958.

The cost and difficulty of making chills and back supports for complicated titanium welds are obviated by the arc welding method described. The joint is chilled with thin, ductile liquid-cooled chills shaped to make close contact. Annealed copper or aluminum are the preferred materials. Inert gas is confined by shrouds on the front and by backing strip behind.

2. Recommended practice for arc welding titanium metals. CANADIAN MACHINERY AND METALWORKING v. 72, n. 6, p. 153 – 154, 156, 158, June 1961.

Titanium alloy grades suitable for arc welding are listed, and a table of data for six welded joint designs is presented covering electrode size and type, thickness of sheet, weld passes, root opening, angle of bevel, land, and whether to use filler wire. Prior edge and surface preparation of sheet is important. Conventional automatic or manual equipment may be used, dc machines with straight polarity being preferred. Adequate shielding with helium, argon or their mixtures is essential, and is supplied through backing bars in open-air welding. Helium permits greater penetration and faster welding, but argon is favored because weld control and metal transfer are better. Titanium or titanium alloys may be used as filler wire. Bend tests are used to evaluate shielding conditions.

3. Bishop, E.

Technological and metallurgical aspects of electro-slag welding. WELDING AND METAL FABRICATION v. 27, n. 12, p. 461 – 467, Dec 1959.

Titanium is currently being welded in the U.S.S.R. by the electro-slag welding process. Either of two fluoride fluxes is available, but their compositions are unknown. Advantages and characteristics of the process are considered. Efficiency is high and increases with weld thickness. The molten metal thrown off as droplets from the electrode does not react appreciably with the slag on its way to the weld pool, but may pick up gas contaimination unless inert atmosphere is provided (a small flow suffices). Data are tabulated. 22 references.

4. Blum, B. S. and Phillipps, E. J.,

assignors to Curtiss-Wright Corporation.

U.S. Patent 2, 914, 848. U.S. PATENT OFFICE.

A method of joining a titanium part to another part includes abutting the parts with brazing alloy adjacent to the abutting surfaces, and brazing at about 1600°F. The alloy is silver base with 1-20% Sn and 1-6% Al. A diagram is shown

5. Boegehold, A. L. and Vigor, C. W.,

assignors to General Motors Corp., Detroit, Mich. U. S. Patent 2, 906,008.

A brazed titanium assembly has a plurality of titanium parts joined together through a central Ti-Ni hypereutectoid area bounded by a Ti-Ni hypoeutectoid area. The eutectoid-free structure is shown in a micrograph.

6. Brazing Titanium.

Imperial Chemical Industries, Ltd.,

London, England. British Patent 809,125.

Abstracted in: LIGHT METALS v. 22, n. 253,

p. 107, APR 1959.

Titanium or its alloys can be brazed with a titanium-base eutectic alloy containing 62% Ti, 28% Ni and 10% Cu. The ternary brazing alloy has a melting point of 1020° – 1030°C.

7. Brothers, A. J., et. el.

WELDED TITANIUM CASE FOR SPACE-

PROBE ROCKET MOTOR. Jet Propulsion

Laboratory. Rept. No. 30-8(SPIA File No.

S60-375), Sep 1959, 8 pp. incl 11 figs, 2 tables,

Rept. No. 30-8(SPIA File No. S60-375).

Contract NASw-6.

The paper describes the fabrication of a 6-in.-diam., 0.025-in.-wall rocket-motor from the 6Al-4V titanium alloy. The rocket-motor case, used in the fourth stage of a successful JPL-NASA lunar-probe flight, was constructed using a design previously proven satisfactory for Type 410 stainless steel. The nature and scope of the problems peculiar to the use of the titanium alloy, especially welding methods and weld porosity, are described. Use of titanium reduced the weight by 34%.

8. Brothers, A. J., et. al.

Welded titanium case for space-probe rocket

motor. WELDING JOURNAL v. 39, n. 3,

p. 209 – 214, Mar 1960.

Ti-6Al-4V was fabricated into a rocket motor for the fourth stage of a successful lunar probe flight (Juno II) by adapting methods used for Type 410 stainless. Welds for the

support ring and forward and aft domes were made by semiautomatic methods and the longitudinal weld was made manually. Filler wire where needed was Ti-6Al-4V. The circumferential weld was made in an inert gas enclosure after an argon-purged open-topped trough proved impractical. Weld porosity was a problem even with scrupulous precleaning. Burnthroughs, tungsten inclusions and incomplete penetration also occurred. Removal of porosity by remelting the weld area was not compl etely successful in the two attempts made. Photographs are shown.

9 Brothers, A. J., Martens, H. E. and H. L. Wood.

BAND PROPERTIES OF WELDED HIGH-STRENGTH TITANIUM ALLOY SHEET. Jet Propulsion Laboratory, California Institute of Technology, Pasadena, Calif., Rech. Rept. No. 32-39 (File No. F428), 30 Jan 1961, 12p. incl. 8 figs., 5 tables.

Contract NASw-6.

Six titanium sheet alloys with a 0.2% yield strength of greater than 150,000 psi were welded with nine different filler wire alloys. A combination three-point free- and guided-bend test was used to determine the ductility of the weld joints. Welding after aging resulted in larger fracture deflections and smaller modulus of rupture values than weld-prior to aging. On a relative weldability basis the alloys in decreasing order of wel ia-bility would be rated: 2.5Al-16V, B120VCA, 6Al-4V, 3Al-6Mo, 4Al-3Mo-IV, and Rs140.

10. Davis, H. C.

Silver-aluminum alloys for brazing titanium and its alloys. METALLURGIA v. 60, n. 361, p. 205 – 211, Nov 1959.

A laboratory sutdy of brazing titanium to itself and to Ti-6Al-4V and Ti- Al-2.5Sn emphasized brazing alloys. Results were evaluated by tensile, compressive and corrosion tests. The aim of the work was the development of sandwich panels with titanium cores. Al-30Ag-1Ni and Al-30Ag-1Mn were the most successful brazes, with the optimum brazing conditions being 650°–660°C for 10-15 min in vacuo or argon. Binary alloys were inadequate. Tables and graphs are shown. 3 references.

11. Didkovskii, V. P.

Electroslag welding of thick titanium pieces

with the aid of a melting nozzle.

AVTOMATICHESKAYA SVARKA v. 14, n. 5,

p. 91–92, May 1961. (In Russian)

Forged titanium pieces 70 – 150 mm thick were welded by the electroslag method, the slag bath being protected with argon and the 3 mm welding wire directed by a melting nozzle made of 12 mm thick plate of the same composition as that of the welded pieces. The gap left between the latter was 26 mm. Lower currents were needed than with the usual thick electrodes. No contamination of the weld seam occurred. The welds had very satisfactory strength and plasticity characteristics. Seams 1500-2000 mm long were readily obtained on workpieces over 40 mm thick.

12. Faulkner and Voldrich, C. B.

INTERPRETIVE REPORT ON WELDING

TITANIUM AND TITANIUM ALLOYS.

Welding Research Council of the Engineering

Foundation, New York, New York, rept. no.

56, Dec 1959, 20p., 38 references, 16 figures,

24 tables.

Welded titanium and titanium-alloy assemblies are used in airframes, jet engines, and chemical equipment. These assemblies are fabricated from sheet,bar, plate, and forgings, and joined by the use of inert-gas-shielded metal-arc, spot-, seam-, flash-, and pressure-welding operations. It has not been possible to adapt the other common welding processes such as gas welding and arc welding with active gases, coated electrodes, or under fluxes, to these metals because:

(1) These metals are extremely reactive when heated to welding temperatures and readily react with air and most elements and compounds, including all known refractories.
(2) The ductility and toughness of titanium welds are reduced by the presence of small amounts of impurities, especially carbon, hydrogen, and oxygen.

12. (Cont'd.)

In spite of their high reactivity and low tolerance for impurities, these metals are readily adaptable to spot-, seam-, flash-, and pressure-welding operations. Normal welding procedures are satisfactory with these processes.

Alloy selection is important in planning welded titanium assemblies. Welded joints in some alloys have excellent mechanical properties, whereas joints in other alloys are too brittle to be useful. The alpha-type alloys do not respond to heat treatment and their mechanical properties are affected only slightly by variations in microstructure. Many of the alpha-beta-type alloys are severely embrittled by welding operations. Special consideration is required in selecting these alloys for welding applications. Only one beta alloy is presently available. Welded joints in this alloy are extremely ductile in the as-welded conditions, but their strengths are low. When heat treated to increase strength, weld ductility decreases.

Although titanium and titanium alloys may be welded to themselves and each other, it is difficult to weld them to other metals. Titanium is severely embrittled by the formation of brittle intermetallic compounds, or excessive solid-solution hardening when highly alloyed with most of the common structural metals. Such structures are formed when titanium is welded to other metals with processes that melt both base metals. As a result, the only reliable method for joining titanium to other metals is by means of brazing operations. However, there is a great deal of interest in the use of welding for this purpose and sufficient success has been obtained in the laboratory so that development of a method does not appear hopeless.

13. Faulkner, G. E. and Voldrich, C. B.

THE WELDING OF TITANIUM AND TITANIUM ALLOYS. Battelle Memorial Institute. Defense Metals Information Center, rept. no. 122, (PB 151079) 13 Dec 1959, 70p.

Titanium airframe, jet engine, missile and chemical apparatus components are fabricated by welding. Proper welding methods and selection of alloys with required

13. (Cont'd).

weld-joint properties are important. Chemical and metallurgical factors that influence this choice are considered. Data are presented on surface preparation, quality control mechanical properties of welded joints, and effects of heat treatment and high temperature. 38 references.

14. Faulkner, G. E. and Lewis, W. J.

RECENT DEVELOPMENTS IN TITANIUM BRAZING. Battelle Memorial Institute, Columbus, Ohio, DMIC Memorandum No. 45, PB 161195, 4 Mar 1960, 5p. 4 references.

Most of the recent development programs on titanium brazing have been conducted to establish fabricating methods for brazed titanium sandwich structure. In these programs, brazing filler metals that do not attack the titanium are required to prevent embrittlement of the thin foil in the core. As a consequence, much of the effort in these programs has been devoted to the development of improved brazing filler metals.

Brazing filler metals: At the present time several brazing filler metals that do not alloy, or alloy very slightly, with titanium are known.

One such series of brazing filler metals in the silver-lithium alloys. The compositions of the silver-lithium alloys range from about 0.5 to 3 percent lithium, but alloys that contain 2 to 3 percent lithium have been used more as brazing filler metals than the others. The brazing temperatures for these alloys range from 1400 to 1450F. At these temperatures the filler metals readily wet and flow on titanium with a minimum of alloying.

One problem with the silver-lithium alloys, however, is that joints made with these alloys do not have good oxidation resistance when heated to elevated temperatures (800°F) in air, and joint strength is severely impaired by such treatments. In addition, joints made with silver-lithium alloys have poor corrosion resistance to salt-spray environments.

In an attempt to improve the oxidation and corrosion resistance of joints brazed with silver-lithium filler metals, studies were made at Convair, Ft. Worth, Texas, in which the brazing filler metals were coated with another metal prior to brazing. Coatings of silver, zinc, iron, and gold were unsatisfactory. Coatings of palladium and rhodium were beneficial, and paltinum and nickel were best. However, numerous tests with these coatings proved that they were not so satisfactory as desired.

14. (Cont'd)

Another series of alloys that appears promising are the silver-aluminum alloys. These alloys were developed at Convari, Ft. Worth, Texas, after the poor oxidation and corrosion resistance of the silver-lithium joints were discovered. These alloys also wet and flow on titanium with a minimum of alloying.

Two compositions of silver-aluminum alloys have been studies: 87.5 percent silver, 12.5 percent 3S aluminum (Dynabraze A) and 95 percent silver, 5 percent 3S aluminum (Dynabraze B). Brazing temperatures for these alloys are about 1450°F for Dynabraze A, and 1600°F for Dynabraze B. The strength of joints made with these filler metals is not impaired by exposure at 800°F in air for 100 hours or exposure to salt spray for 50 hours.

The Curtiss-Wright Corporation, Research Division, Quehanna, Pennsylvania, also has introduced to the market a new brazing filler metal and brazing flux for titanium. With this filler metal and flux, oxyacetylene torch-brazed joints may be made without attacking the titanium. The trade names of the brazing filler metal and flux are Curtisol and Curtiflux, respectively.

Report also discusses brazing methods, mechanical properties of brazed joints, and effects of brazing cycles on base-metal properties.

15. Faulkner, G. E.

NEW WELDING PROCESSES FOR TITANIUM.

Paper presented at Sixth Annual Titanium

Metallurgy Conference, New York University,

12 – 13 Sep 1960, 7p.

The objective of this discussion is to review the potential of these new metals-joining techniques as methods for joining titanium. Included will be discussions of modified inert-gas-shielded conservable-electrode welding, electron-beam welding, high-frequency resistance-welding, foil seam-butt welding, ultrasonic welding, and diffusion bonding. There also are many other new or modified processes including electroslag welding, arc-spot welding, and friction welding, but they will not be discussed in detail.

Information was presented on how the processes work, potential applications, limitations, and what refinements can be expected in the future. This type of information will be useful in placing proper emphasis on the new processes.

Discusses, inert-gas-shielded consumable-electrode welding; electron beam welding; foil-seam-butt welding; ultrasonic welding; high-frequency resistance welding; diffusion bonding; and other processes.

16. Franco-Ferreira, E. A. and Patriarca, P.

THE INERT GAS SHIELDED METAL ARC WELDING OF TITANIUM. U.S. Atomic Energy Commission, rept. no. ORNL-2612, 17 Mar 1959, 59p.

The need for a remote repairing of leaks in a nuclear reactor prompted a study of SIGMA welding of titanium. The program concentrated on developing techniques for single-pass full-penetration square butt welding of plates in the downhand position. This kind of welding is successful on titanium if process variables are controlled rigidly. It is thus applicable to the automatic or semi-automatic welding needed for remote repairing. The discussion of results is supported by graphs, photographs and tables. 8 references.

17. Gurevich, S. M. and Didkovskii, V. P.

Certain questions concerning the electroslag welding of titanium. AVTOMATICHESKAYA SVARKA v. 10, n. 3, p. 85 – 91, Mar 1957. Abstracted in: METAL PROGRESS v. 75, n. 6, p. 200, 202, June 1959. (In Russian)

The electroslag welding process is used in the USSR to join heavy titanium sections since submerged-arc, SIGMA and pressure welding are less effective. In electroslag welding, copper molds contain the oxygenless flux and the metal within the joint. The progression of the weld puddle is upwards. An argon shield is used at a flow rate of 6.3-8.4 cu ft/hr. The welds have a coarse acicular at structure unless energy input is kept low.

18. Gurevich, S. M.

The metal of the seam in arc welding of titanium alloys. AVTOMATICHESKAYA SVARKA v. 11, n. 10, p. 3 – 13, Oct 1958. (In Russian)

18. (Cont'd).

While welding under a flux is the best procedure for medium-thickness articles, slag-electric welding is recommended for thicknesses above 30-40 mm. Electrodes of technically pure titanium are proposed for arc welding monophase α-Ti alloys or alloys containing 2 - 3 percent β -stabilizing metals. Alloyed electrodes, differing chemically from the base metal, should be employed in welding medium-alloyed two-phase titanium alloys. 20 references.

19. Gourd, L. M. and Copleston, F. W.

Welding the reactive metals. WELDING

ENGINEER v. 44, n. 10, p 43 – 44, Oct 1959.

Welding titanium and zirconium is complicated by the protection necessary to the weld pool and all of the component parts. The tungsten arc-inert gas shield is the method used, and may be accompanied by an auxiliary shield and special jigs. If open air welding is used, jigs must provide maximum chilling next to the weld. In quantity production, an argon chamber is feasible, especially for complex parts. Filler wire should be avoided if possible in open air welding, and therefore edge, corner and flanged butt welds are preferred.

20. Gourd, L. M. and Copleston, F. W.

Welding techniques for rare metals.

COMMONWEALTH ENGINEER v. 47, n. 4,

p. 49 – 50, 5 Nov 1959.

Preventing embrittlement is the main concern in fusion welding titanium and ziroconium. This may be achieved by correct use of inert-gas shielding and specially designed jigs which provide maximum chilling. Blanged, butt, edge and corner welds should be preferred since filler wire is not required. The tungsten arc spot welding process may be used to make joints in the lighter gages.

21. Gurevich, S. M.

Problems of welding titanium and other chemically

active metals. SCHWEISSTECHNIK v. 11, n. 9,

p. 394 – 398, Sep 1961. (In German)

21 (Cont'd).

Mechanical properties of titanium-alloy welded joints are examined in relation to the composition of the electrodes, the heat consumed, and the presence of β stabilizers in the welded material. The recently introduced electron beam welding technique will be particularly suited to titanium welding because of the almost complete absence of gas penetration, and the high concentration of heat ensuring thin weld seams and unaffected welded pieces. 4 references.

22. Handova, C. W.

Welding titanium for missiles. A report of some American works practice. SHEET METAL INDUSTRIES v. 36, n. 385, p. 359 – 360, May 1959.

Tig welding is the only fusion process acceptable for joining titanium missile components, but the consumable electrode process may be used to weld heavy titanium plate. Butt joints are better in fusion welding because they carry a greater load and are easily inspected. However, they cannot have true alignment without precise trimming, fit-up and jigging. Two ways of joining thick and thin sections are shown. Lap joints require less precise fit-up but have other limitations. Tee joints are seldom used. Brazing and soldering of titanium are considered briefly. Diagrams are shown.

23. Hanink, D. K. (assignor General Motors Corp., Detroit, Mich.) Method of uniting aluminum to titanium and product thereof. Canadian Patent 573, 091.

Abstracted in: CANADIAN PATENT OFFICE RECORD v. 87, n. 13, p. 2913, 31 Mar 1959.

An aluminum-base alloy is bonded securely to a metal containing at least 50% Ti by immersing an article of the latter in a fused salt bath activated by aluminum, immersing the part in molten aluminum-base alloy, and then casting the aluminum-base alloy part in contact with the coated titanium alloy. The bath comprises 37-57% KCl, 25-40% NaCl, 8-20% Na_3AlF_6 and 0.5-12% AlF_3. The temperature of the bath is 1200°-1600°F (preferably 1300°-1400°F) and that of the molten alloy is 1150°-1600°F (preferably 1250°-1325°F).

24. Hartbower, C. E.

ADVANCING THE TECHNOLOGY OF WELDING

TITANIUM. Watertown Arsenal Laboratories.

Technical papers presented at Watertown Arsenal,

Watertown, Mass., 9 –10 Feb 1960, p. 43-46,

4p., 11 references.

Techniques for welding and testing titanium have been developed which take into account (1) the detrimental effect of the interstitial elements introduced to the weld through either the filler wire, base material, or welding atmosphere, and (2) the limit of substitutional beta-stabilizing elements for toughness in both weld and heat-affected base metals. The technique of using unalloyed filler wire for joining alpha-beta-alloy base materials was originally developed at Watertown Arsenal Laboratories and is now generally used by industry for applications where maximum toughness and ductility are desired in the weld joint.

For an understanding of the problems associated with the joining of titanium and titanium alloys, one must consider certain aspects of the physical metallurgy of titanium. First and foremost is the high reactivity of titanium when heated to welding temperatures. Second, one must consider the extreme sensitivity of titanium to embrittlement by small amounts of impurities. The third major consideration is not peculiar to the welding of titanium, but is an important consideration in welding all metals; viz., the effects of the weld thermal cycle on mechanical properties.

Discusses

Reactivity and Diffusion-Rage Considerations

Effects of Impurities

Effects of Alloying Elements – The effects of alloying elements on the allotropic transformation of titanium are extremely important in welding operations. Alloying elements that are commercially important for titanium include: the alpha-stabilizing elements, aluminum, carbon, oxygen, and nitrogen; the beta-stabilizing elements, chromium, iron, manganese, molybdenum, vanadium, tantalum, and columbium; and tin which is neither an alpha nor beta stabilizer.

Only one all-beta alloy is available commercially; viz., Ti-13V-11Cr-4A1. Arc-welded joints in this alloy are generally very ductile in the as-welded condition, but have low strength. Postweld heat treatment improves the strength but ductility tends to be low. Extensive studies are under way to develop heat treatments for strengthening arc-welded joints in the beta alloy without excessive embrittlement.

25. Herb, C. O.

Welding ultra-thin and thick materials together.

MACHINERY v. 66, n. 11, p. 128 – 130,

July 1960.

Welding processes and achievements of Ryan Aeronautical Co. (San Diego) include spot welding of thin titanium tubes into a three-legged weldment and resistance welding of ten thin sheets of B 120VCA. Photographs are shown.

26. Hoefer, H. W.

Fusion welding of titanium in jet engine applications.

HAWKER SIDDELEY TECHNICAL JOURNAL

v. 1, n. 1, p. 19 – 27, Winter 1958.

Problems involved in the fusion welding of titanium are discussed, and equipment and techniques developed to overcome these problems are described. Detailed descriptions and illustrations are given of equipment designed to prevent weld contamination and embrittlement in a wide variety of applications. Special automatic welding techniques for eliminating porosity are noted. These are based on higher welding speeds and reduced weld chill. Joint design and fixturing are also considered. Joint strength data for titanium and some alloys are given. 5 references.

27. Hull, W. G.

Fusion welding of titanium and its alloys I.

WELDING AND METAL FABRICATION

v. 29, n. 1, p. 24 – 31, 36, Jan 1961

Much attention has been given to developing satisfactory technqies for fusion welding of titanium. A critical appraisal of the current situation in titanium fusion welding is presented, taking into account the basic problems involved. Atmospheric contamination of parent and weld metal may be prevented by use of vacuum-purged or flow-purged welding chambers. The former are costly but give excellent welds if evacuation below 0.2 mm Hg is achieved. Continued efficiency depends largely on supervision and maintenance. The latter type may be either rigid or collapsible, although little literature on the performance of collapsible chambers is available. Flow-purged and vacuum-purged systems have similar limitations, i.e. low duty cycle, inconvenience in handling torch, and restricted work size. Larger work welded in the open air requires protection from the atmosphere. Various methods of shielding with flows of argon and backing strips are available. Factors governing the degree of coverage by a flow of argon from a given nozzle are treated analytically.

28. Hull, W. G.

Fusion welding of titanium and its alloys II.

WELDING AND METAL FABRICATION

v. 29, n. 2, p. 72-72, Feb 1961.

Most welded titanium assemblies are made from thin sheet, to which the Tig process is readily and commonly applied. Practical aspects such as electrode arrangements, dc power source, use of a current-decay circuit to avoid cratering at the end, joint protection, ancillary equipment and jigging arrangements are discussed. Before jigging, edges and adjacent surface are cleaned. Solvent degreasing is usually adequate but mechanical cleaning or pickling may be necessary. Tack welding is often a suitable alternative to elaborate jigging. Jigging for underside protection, longitudinal seams and corner welding is considered. Welding is not a feasible method of joining titanium linings to mild steel chemical equipment, but mechanical methods may be used. Diagrams are shown.

29. Hull, W. G.

Fusion welding of titanium and its alloys III.

WELDING AND METAL FABRICATION

v. 29, n. 3, p. 111 – 113, Mar 1961.

In welding thick titanium sheet by the Tig method, gas shielding difficulties may be minimized by multi-pass welding using small stringer beads, grooved edges and filler of pure grade. Self-adjusting arc-welding has grown in importance and has been tested in welding titanium alloys. One such test is described. The process should be considered where thickness exceeds 3/16-in and where joint design is amenable to mechanized open air welding. Where furnace stress-relieving is impractical, local stress relief by torch heating is recommended. An oxidizing flame should be used. Porosity and appearance of the weld are indicators of weld quality.

30. Hull, W. G.

Fusion welding of titanium and its alloys IV

WELDING AND METAL FABRICATION

v. 29, n. 6, p. 262 – 266, June 1961

Weldability vs. kind and degree of alloying addition is discussed for titanium and its alloys. β stabilizers generally confer poor weldability because of the precipitation

of decomposition phases. Interstitial additions are undesirable and keeping the contamination from them at a low level is one object in welding. In $\alpha + \beta$ alloys the presence of aluminum is beneficial to weldability, as shown by many studies. Welded metal has good ductility. Data are tabulated. 45 references.

31 Inglis, N. P. and Taylor, E. A.

Welding in the non-ferrous field.

BRITISH WELDING JOURNAL v. 8, n. 9,

p. 419 – 436, Sep 1961.

A review of welding technology for nonferrous metals covers information on titanium and zirconium. The welding of titanium is of great importance to its application for chemical processing equipment. The problem of atmospheric contamination as influenced by welding process and joint design is discussed. Weld porosity occurs rarely and has no significant effect. It is probably due to argon trapped at abutting edges. Resistance spot and seam welding are especially suitable for titanium, due to its high electrical resistance. Equipment and processes for welding titanium may generally be applied to zirconium, but the argon arc method is used to give the high quality required for reactor work. Photographs are shown.

32. Itelson, G. M.

Corrosion resistant welded titanium pumps.

TSVETNYE METALLY v. 34, n. 2, p. 74-78,

Feb. 1961. (In Russian)

Production of welded titanium pumps was proposed as a means of obtaining apparatus for metallurgical processes involving acidic solutions with a variety of metal sulfates and chlorides. Service life of steel alloy pumpos was short. Symmetrical halves of pressed titanium alloy plate are welded together to make the volute. The pump cover is machined from a forging, as are most of the connecting flanges for the pump. The impeller is made from rolled and forged titanium and is of welded construction. Semi-automatic Tig welding equipment and a titanium degassing wire are used in joining. Diagrams are shown.

33. Johnson, E.W., Itch, F. R. and Readal, R. L. assignors to Westinghouse Electric Corp. Metals joining apparatus. U. S. Patent 2, 933, 594. Abstracted in: U. S. PATENT OFFICE. OFFICIAL GAZETTE v. 753, n. 3, p. 747–748, 19 Apr 1960.

Group IVb, Vb and BIb metals may be joined by providing a dc arc discharge to clean one surface before applying a brazing material. The second surface is then engaged and caused to join by heating.

34. Jones, J. B. McKaig, H. L. and Thomas, J. G. Aerojets Inc., West Chester, Pa. INVESTIGATION OF ULTRASONIC WELDING OF ALL-BETA TITANIUM ALLOY. Rept. no. RR-61-77 (Final) (Includes information from Monthly Progress Rept. no. 7, Jan 1961 (File no. F987) not abstracted). Sep 1961, 34p. incl. 19 figs., 5 tables. Contract NOw 60-0643.

The results of this present research demonstrated the feasibility of ultrasonic spot-type welding of thin gages of conditioned all-beta titanium alloy and fabrication of structural components with high strength: weight ratios. In the course of this work, the ultimate tensile strength of beta-stabilized titanium alloy was improved by heat-treating and/or cold-rolling. The strength: weight ratio of thin strip was increased to approximately 1.3 million by heat treatment (solution-tested and aged) alone. When the STA material is subsequently cold-rolled, the strength: weight ratio increases to slightly more than 1.5 million.

The results of the strength and degradation measurements indicate the sensitivity of this material to the welding conditions employed in fabrication. The more rapid material degradation encountered in the higher strength welds is probably related to the welding temperatures achieved by interfacial heating during the period of ultrasonic exposure. Examination of weld sections indicated that temperatures sufficiently high to exceed the transformation temperature of the alloy occurred during welding, and the resulting retained beta structure in the weld zone developed a characteristic block-like pattern. The degree of heating was sufficient in most cases to eliminate the cold-work strengthening of the cold-rolled material and to degrade the precipitation-strengthening of the aged material locally in and near the weld zone.

34. (Cont'd)

Successful multi-ply elements were assembled by the through-welding and the ply-by-ply ultrasonic welding techniques. In general, insertion of an interleaf of 0.0005-in. unalloyed titanium at the weldment interface successfully reduces the energy required to produce a satisfactory bond. The direction of the vibratory motion of the tip, whether applied parallel or transverse to the rolling direction of the thin strip, does not significantly change the strength of the spot-type weld.

The substitution of a hardened tool-steel tip for an Inconel X tip resulted in spot welds of much greater strength and in some cases variability was also reduced. The importance of clamping force in the coupling of the sonotrode tip to the weldment face and in the efficient delivery of energy to the weld zone was demonstrated.

35. Keel, C. G.

Properties and welding characteristics of new metals and alloys I, II. ZEITSCHRIFT FUER SCHWEISSTECHNIK (JOURNAL DE LA SOUDURE) v. 49, n. 2, p. 32 – 36, 10 Feb 1959, n. 3, p. 70 – 80, 10 Mar 1959. (In German and French)

An introductory section presents a brief survey of the properties of titanium, zirconium, hafnium, vanadium, molybdenum and other metals now increasingly employed in heat-resistant alloys and in the construction of nuclear reactors. A review is then given of the problems associated with the welding of titanium and its alloys. A protective-gas chamber for titanium welding is illustrated. Recent progress in brazing titanium and its alloys is noted, particularly the use of eutectic Al-Si electrodes or the especially effective silver alloy brazing materials.

36. Koecher, R.

Examples of welded parts made on non-ferrous metals. SCHWEISSEN UND SCHENEIDEN v. 11, n. 6, p. 224-227, June 1959

In an investigation of welded structures of various non-ferrous metals, including nickel-molybdenum alloys and titanium, it was found that the selection of suitable

welding conditions greatly influences the final results. It is of particular importance to reduce the effect of heat on molybdenum-nickel alloys during welding. In the case of welding titanium, a protective argon atmosphere should be used to get satisfactory welding joints.

37. Krekeler, K. and Verhoeven, H.

Studies on welding of titanium.

FORSCHUNGSBERICHTE DES LANDES

NORDRHEIN-WESTFALEN, v. 692, 51p.

1959. (In German)

Experiments on welding of titanium and its alloys led to following recommendations. Edges to be welded should be previously pickled and, in welding, placed very close together. The electrode should be held as close as possible to the seam. The influence of argon on the strength of the weld is small. Recommended heat treatment is 1 hr annealing at 700°C followed by cooling in air. 24 references.

38. Kutchera, R. E., assignor (to Titanium

Metals Corp. of America.) Welding Titanium.

U.S. Patent 2, 985, 747.

A titanium article may be welded to a ferrous body to whose surface a vanadium inlay has been applied. An edge of the titanium may be welded to the inlay. A diagram is shown.

39. Lachenaud, R.

Titanium and its alloys II. Welding of titanium and

its alloys. SOUDAGE ET TECHNIQUES CONNEXES

v. 14, n. 11/12, p. 420 – 431, Nov – Dec 1960.

(In French)

39. (Cont'd)

Investigations were carried out on the Ti-alloy TA5E (Ti-5A1-2.5Sn) and on the spot welding of Ta6V (Ti-6A1-4V). In the case of welding the TA5E alloy, particular precautions have to be taken which, though foreign to those used to work with steel and light metals, are quite customary in the welding of superrefractory materials such as niobium, tantalum and molybdenum. Spot welding, on the other hand, does not cause special problems, and is actually simpler than that of the light metals.

40. Lander, H. J., Hess, W. T., White, S. S.

The Alloyd Corporation, Cambridge, Mass.,

THE ELECTRON BEAM WELDING OF TITANIUM

ALLOYS, Tech. rept. no. WAL 401.54/2

(File No. F755). 10 Mar 1961, 8p. 26 figs.

Contract No. DA-19-020-ORD-5246.

Five different titanium alloys have been successfully electron beam welded in a variety of fusion zone widths varying from 0.050 to 0.300 inches. Impact resistance of fusion zones was found to be compatible with or higher than base plate values. Similarly, an increase in fusion zone ultimate strength, as compared to that of base plate, was noted. Some strength losses and general incremental ductility losses were reported. These results are correlated with interstitial gaseous content.

This paper will be presented at the 17th meeting of the JANAF Solid Propellant Group, 25 May 1961 (DLB)

41. Laurenson, T. M.

Eliminating contamination is a prime consideration

when welding titanium. WELDING ENGINEER

v. 44, n. 10, p. 46 – 49, Oct 1959.

The pre-welding procedures for eliminating contamination of titanium include machining or filing the edges, pickling off scale with HNO_3-HF solutions, wire brushing, and degreasing. Grinding should be avoided if possible because the heat resulting causes contamination. To prevent contamination during welding, the typical setup

includes torch nozzle, trailing cup, back-up bar and chill bars. Exact gas flow rate is diff'cult to specify, but visual inspection is a clue to adequacy. Machine settings should be low to produce 100% penetration. A piece of scrap titanium should be burned in a weld chamber after purging to consume residual oxygen. A table of recommendations for manual welding is given.

42. McDowell, K. H. and Weeks, D. A.

A practical approach to resistance welding.

BRITISH WELDING JOURNAL v. 6, n. 9,

p. 381 – 395, Sep 1959.

The basic principles of resistance welding are discussed, and the application of the gas-turbine industry are considered. When welding titanium sheet, the closeness of the sheets and the speed of welding should prevent weld contamination. High penetration is often more apparent than real, since differentiation between weld and heat-affected zone is difficult. Post-weld heat treatment may widen the range of weldable titanium alloys. Micrographs are shown. 8 references.

43. Newburn, J. M.

Fusion welding of the less common metals. In

AUSTRALIAN ATOMIC ENERGY SYMPOSIUM

p. 216 – 220. 1958.

A literature review shows that hafnium, titanium, vanadium and zirconium can be joined at least to themselves by the fusion welding process, if suitable precautions against atmospheric contamination are taken. Use of the inert gas shielded arc procedure gives ductile welds. Hafnium has been welded to zirconium, Zircaloy-2 and titanium, in the latter case producing welds of greater strength than the parent metals. Mechanically satisfactory zirconium welds have been produced outside inert gas chambers. Only brief mention of the fusion welding of vanadium is found in the literature. Of the commercial titanium alloys, only three are recommended for welding: Ti-1. Ti-1.5Al-3Mn, Ti-2.25Al-3.25Mn and Ti-6Al-4V. β alloys have poor mechanical properties as-welded because of partial transformation during the weld cycle. Effects of contamination by various gases has been much studied. 66 references.

44. Nolen, R. K., et al.

Spot welding of titanium alloys. WELDING JOURNAL v. 38, n. 5, p. 219s – 221s, May 1959.

Welding parameters were determined for spot welding annealed Ti-4Al-3Mo-1V and Ti-5Al-2.5Sn and heat treated Ti-6Al-4V and Ti-4Al-3Mo-IV. Results are shown on curves. The optimum current is higher for these materials than for annealed Ti-6Al-4V. Differences are attributed to differences in electrical conductivity, but the requirement generally increases with the amount of phase. Other welding parameters are similar to those determined for annealed Ti-6Al-4V. Tension-shear strengths are also similar. All spot weld readily.

45. Oyler, G. W.

Heliarc Welding increasing.

MISSILES AND ROCKETS v. 5, n. 48, p. 69, 23 Nov 1959.

Heliarc welding has been used to test the weldability of hafnium, vanadium, molybdenum and zirconium. In production welding of titanium an argon trailing shield is used for the weld puddle in addition to the regular shielding cup because of reactivity at welding temperatures and sensitivity to embrittlement. Zirconium and hafnium must be welded in an inert atmosphere chamber.

46. Ruedinger, K.

The welding of titanium.

DECHEMA MONOGRAPHIEN v. 36, n. 556 – 575, p. 130 – 138, 1959

The problems in welding titanium are discussed. Most of the commercially available titanium alloys cannot be considered weldable. Those alloys are weldable in which no phase develops in the cooling process. Various precautions have to be taken, particularly because titanium and its alloy have a high affinity for the gases in the atmosphere, which produce brittleness. The various possible precautions, and their effects on the weld properties are discussed. 5 references.

47. Ruedinger, K.

Essentials of titanium welding in manufacturing containers and other equipment. INDUSTRIE-ANZEIBGER v. 83, n. 41, p. 701 – 705, 23 May 1961. (In German)

The main features of titanium welding are described, including the protection of the weld with argon (purity and consumption of the gas), the welding current as a function of the thickness of the welded titanium sheet, and properties of the seam (hardness, plasticity, porosity). Photographs illustrate a variety of welded constructions from titanium (heating coils, distillation columns, titanium-covered rolls, etc.). 13 references.

48. Salt, A. E. and Taylor, E. A.

(assignors to Imperial Chemical Industries, Ltd.)

IMPROVEMENTS IN BRAZING TITANIUM OR TITANIUM BASE ALLOYS Belgian Patent 546,627, 23 Oct 1959, 6p.

Titanium or titanium-base alloys are brazed by a Ti-Fe eutectic alloy which is formed in situ by melting the constituents of the alloy. The molten mixture is then diffused into the parts to be brazed.

49. Savas, J.

DEVELOPMENT OF FUSION WELDING TECHNIQUES FOR TWO INCH THICK TITANIUM PLATES (GRADE RS70, COMMERCIALLY PURE). Republic Steel Corporation, South Division, Titanium Research Laboratory, Canton, Ohio. USN, Bureau of Aeronautics, First bimonthly report, July 1960, 2 p. Contract No. NOas 60-6091-F

49. (Cont'd).

Report covers the preliminary work initiated in arranging the rolling and welding of 2-inch thick plate sections of commercially pure titanium (RS70 grade). The work under this contract is part of an over-all program set up to evaluate titanium and titanium alloys as potential materials of construction for hull plates of deep-diving submarines.

50. Savas, J.

DEVELOPMENT OF FUSION WELDING

TECHNIQUES FOR TWO INCH THICK TITANIUM

PLATES (GRADE RS70, COMMERCIALLY PURE).

Republic Steel Corporation, Canton, Ohio,

Second bimonthly report, USN, Bureau of Aeronautics,

Sep 1960, 2p. Contract No. NOas 60-6091-F

The purpose of this contract is for an over-all program to evaluate titanium and titanium alloys as potential materials of construction for hull plates of deep-diving submarines.

During the second monthly reporting period, the following steps were undertaken:

(1) The RS70 material required under items 1, 2, and 4 of the contract was rolled to 2-inch-thicknesses and is being tested prior to torch cutting to the section sizes called for by this contract.
(2) The welding fixture required for this program was delivered and set up.
(3) The RS55, 0.063-inch-diameter welding wire was fabricated, and delivery is expected within 10 days.

51. Savas, J.

DEVELOPMENT OF FUSION WELDING

TECHNIQUES FOR TWO INCH THICK TITANIUM

PLATES (GRADE RS70, COMMERCIALLY PURE).

Republic Steel Corporation, bimonthly report 60-6091 f,

Mar 1961, 5p. Contract NOa(s) 60-6091

ASTIA AD-261 883

51. (Cont'd).

Among the subjects considered are arc welding, heat treating and radiographic inspection of titanium plates. Use in ship and submarine hulls is considered.

52. Savas, J.

DEVELOPMENT OF FUSION WELDING TECHNIQUES FOR TWO INCH THICK TITANIUM PLATES (GRADE RS70), COMMERCIALLY PURE).

Republic Steel Corporation, Canton, Ohio,

USN, Final report May 1961, 21p. 6 tables.

Contract No. NOas 60-6091

The following steps were undertaken:

(1) Testing was completed on the first two experimental welds.
(2) The third, fourth, and fifth sets of the 2 x 4 x 24-inch plates were welded, radiographed, and finally sectioned and tested.
(3) An optimum modified double-V joint design was decided upon for the machining and welding of the 2 x 15 x 30-inch plates into a 2 x 30 x 30-inch weldment. The best welding techniques developed during the welding of the first five experimental weldments were used to complete this 2 x 30 x 30-inch weldment. It was then radiographed and shipped to the Navy for explosive bulge testing.

53. Shelley, R. C.

Torch brazing and hard soldering pure titanium in air. WELDING AND METAL FABRICATION v. 27, n. 1, p. 31 – 32, Jan 1959.

53. (Cont'd)

The oxide film which forms on an exposed titanium surface renders the metal extremely unamenable to orthodox fluxes and techniques for brazing and soldering. Titanium joints were successfully made in air by use of a flux of copper and silver chlorides. At 700° – 800°C the salts deposited a Cu-Ag coating on the titanium surface. Sufficient chlorine is liberated to attack the oxide film, probably removing it as $TiCl_4$, thus permitting "wetting" of the surface by the metal coating to take place without any additional fluxing. The flux contains the two chlorides in such proportion as to give an alloy of approximately eutectic composition (30-35% Cu, 65-70% Ag). An ordinary commercial coal gas and compressed air torch provides the necessary heat. An addition of 20 parts of dehydrated borax to 100 parts of flux acts to clean up some of the copper oxide dross.

54. Shorshorov, M. Kh. and Nazarov, G. V.

Welding and soldering of titanium and its alloys.

In N. V. AGEEV, (ed), "KHIMIYA METALLOVEDENIE I OBRABOTKA TITANA" p. 252-284, Moscow, Izdatel'stvo Akademii Nauk S.S.S.R., 1959. (Itogi Nauki. Tekhnicheskie Nauki 2. (In Russian)

Existing methods of welding titanium reflect the characteristic properties of the metal, its high chemical affinity toward oxygen, hydrogen and nitrogen, and its tendency to form coarse-grained phases at higher temperatures and the brittle α' phase on cooling. The two methods mostly in use are 1) manual or automatic arc welding in an atmosphere of argon or helium by means of either non-fusible (tungsten) or fusible electrodes, and 2) point contact welding in air. The recently introduced automatic welding under a flux is gaining increasing recognition. The authors have assembled in the present work numerous literature data on the various aspects of weiding of titanium and its alloys. A section on soldering titanium is also included. 88 references.

55. Sliney, J. L.

FEASIBILITY OF BRAZING HIGH-STRENGTH SHEET TITANIUM. U. S. Watertown Arsenal Laboratory technical report 401.54/1, Nov 1960, 48p. Abstracted in: NUCLEAR SCIENCE ABSTRACTS v. 15, n. 9, p. 1479, 15 May 1961.

55. (Cont'd).

Lap joints were induction brazed on titanium and -120VCA in a bell jar using low-pressure argon during the heating cycle. No flux was used. Longer overlaps and stronger base metal confer greater load-carrying capacity. Base metal is strengthened by aging after brazing.

56 Taylor, A. F. and Stockdale, J. F.

SOME EXPERIENCES ON THE JOINING

OF THE REFRACTORY METALS. Great

Britain. Atomic Energy Authority. Industrial

Group Rept. no. IGT-TN/S-439, 1959, 20p.

Titanium, zirconium, vanadium but not molybdenum may be spot-and argon-arc-welded satisfactorily in sections up to 0.060 in. Thin sections of molybdenum may be joined only by brazing because the welds are brittle and large-grained. High purity metals and argon are necessary and, while a dry box may give good results, a vacuum-tight apparatus permitting pre-evacuation is desirable. Grain size is minimized by rapid welding. Vanadium and niobium may be welded together. Zircaloy is welded without difficulty. 52 references.

57. Thomasson. H.

Welding the reactive metals.

CANADIAN METALWORKING v. 23,

n. 1, p. 31, 33, Jan 1960.

Disagreement concerning the amount of protection needed in welding titanium, molybdenum zirconium and Zircaloys is noted. The metals exposed to light corrosive conditions can be conventionally Tig welded with inert gas backing on the reverse side. Extreme conditions such as pressurized hot water require the protection of highly purified gases in a dry box. Thorough deoxidation of the parent metal is necessary for successful welding of molybdenum.

58. Titanium wins steel backing.

CHEMICAL WEEK v. 86, n. 21, p. 61 – 62, 64,

21 May 1960.

58. (Cont'd)

The TMCA process for welding titanium to steel uses vanadium discs as the common material to which both may be fusion welded. A hole is first drilled in the steel, the disc is positioned and welded in the hole, and then overlying titanium sheet is welded in place with titanium rod. Vanadium foil can be used for spot or seam welding. Welding in the field is simplified and standard procedures may be used. Use of thin sheets and small discs reduces the cost considerably.

59. Tret'yakov, Karan, A. B. and Tsar'kov, G. P.

The projection welding of articles made of alloy steels and titanium. SVAROCHNOE PROIZVODSTVO.

English Translation: WELDING PRODUCTION

n. 3 p. 59 – 61, Mar 1960.

Projection welding of titanium anchor nuts, branch pipes and nozzles was carried out experimentally. Articles and surfaces to be welded were precleaned. Welding apparatus and conditions are described. Welded articles with regions of partial penetration can be rewelded using 10-15% higher current, and fusion of shoulder edges can be eliminated by use of argon-arc welding with or without filler. Diagrams and a table are given.

60. RESEARCH AND DEVELOPMENT OF ULTRASONIC WELDING. Aeroprojects, Inc., West Chester, Pa. Fourth, Fifth, and Sixth Monthly Progress repts., File Nos. F335, F521, and F522

Oct, Nov, and Dec 1960. 15p. incl. 6 figs, 3 tables.

Contract NOw 60-0643.

Studies of the effect of ultrasonic welding on the strength of 13V-11Cr-3Al titanium alloy continue. Results of three different samples are reported, together with the ultimate tensile strength before welding (UTS), and the percent degradation in UTS when 90% of the specimen width was covered with weld (%degr.). They are: for 10-mil cold-rolled unaged strip, UTS 200 kpsi, 14% degr.; 11-mil cold-rolled aged strip, UTS 240 kpsi, 26% degr.; 4-mil cold-rolled unaged strip, UTS 267 kpsi, 32.5% degr. In each case a "Box design" experiment was carried out to find optimum welding settings, and titanium foil interleafs were used between layers of alloy. The effect of aging after welding is now being determined.

61. van Kann, H.

Welding of titanium

Abstracted in: CHEMISCHE RUNDSCHAU

v. 12, n. 1, p. 320, 1 June 1959.

The most suitable technique for the welding of titanium is that with the usual argon arc device. Satisfactory welding seams may be obtained with suitable selection of the welding conditions. This paper was presented before the Schweisstechnische Tagung in Mannheim, 1958.

62. van Kann, H.

Good mechanical properties can be obtained easily

when tig welding titanium.

WELDING ENGINEER v. 44, n. 6, p. 58 – 60,

June 1959.

West German experience has shown that Tig welding can be used to join unalloyed titanium under nearly the same welding conditions as other materials. The usual torch-nozzle is used but greater diameter, weld speed and current are needed. If filler is needed insheet welding a small foil between sheets is cheap and technically sound. Pre-weld cleaning and inert gas shielding are stressed. Notched weld and corrosion behavior was good.

63. Weare, N. E.

Ultrasonic welding of heat-resisting metals.

WELDING JOURNAL v. 40, n. 8, p. 351s – 358s,

Aug 1961.

Ultrasonic weldability of titanium to titanium, Mo-0.5Ti to Mo-0.5Ti, and both to Type 316 stainless was investigated using the experimental unit described. Steps in the welding procedure are enumerated. Spot welds generally contained cracks at the edge of the bond, probably because of fatigue from the high alternating stresses. Titanium-titanium welds have acceptable cross-tension strengths (comparable to resistance spot welding). All welds involving titanium had a second phase of titanium in the form of slivers extruded from the bond. Mo-0.5Ti welds are weak, but might be improved by preheating and use of high clamping pressure and faster energy input. Tables, graphs and micrographs are shown. 13 references.

64. Wegman, R. F. and Bodnar, M. J.

Bonding rare metals.

MACHINE DESIGN v. 31, n. 20, p. 139 – 140,

1 Oct 1959.

Steel was bonded to titanium and to molybdenum, and titanium was bonded to itself in adhesion test of a rigid polyester and a filled novolac epoxy. The titanium and stainless steel surfaces were degreased and the oxide removed before bonding. Adhesive bond strengths are tabulated.

65. PROPOSED TENTATIVE SPECIFICATION FOR SEAMLESS AND WELDED UNALLOYED TITANIUM TUBING. American Society for Testing Materials, Philadelphia, Pennsylvania . Specification not dated.

7p.

Scope: This specification covers four grades of seamless and welded unalloyed titanium tubing intended for general corrosion-resisting and elevated-temperature service.

Basis of Purchase: Orders for material under this specification shall include the following as required.

(1) Grade number (Sections 4 and 6)
(2) Diameter and wall thickness (Section 13)
    Note: Tubing is available to specified outside diameter inside diameter, and wall thickness (state minimum or average wall), but only two of these parameters may be specified.
(3) Lengths: random or specified cut lengths (Section 13)
(4) Method of manufacture and finish (Sections 3 and 14)
(5) Restrictive chemistry, if desired (Section 4, Table I)
(6) Check analyses, if desired (Section 5)
(7) Special mechanical properties, if desired (Section 6, Table III)
(8) Flattening test (Section 7)
(9) Flaring test (Section 8)
(10) Hydrostatic test (Section 9)
(11) Marking (Section 15)
(12) Packing (Section 16)
(13) Inspection and required reports (Section 17)
(14) Disposition of rejected material (Section 18)

Also discussed were: manufacture; chemical composition; check analyses; tensile properties; flattening test; flaring test; hydrostatic test; test specimens and methods of testing; number of tests; permissible variations in dimensions, etc.

66. Titanium.

In 1958/1959 WELDING DIRECTORY, Cleveland, Ohio., Industrial Publishing Corp., 1957, p. D185–187.

Soldering, welding and brazing methods have been developed for joining titanium parts. Good results are obtained by both inert gas and resistance processes. Weld appearance can give clues to the kine of contamination present. α-Ti alloys are readily welded without preheat. An inset lists precautions for titanium fires. Data are tabulated.

67. Welding titanium.

METAL INDUSTRY v. 94, n. 19, p. 371–374, 8 May 1959.

Spot, flash, pressure and fusion welding are all suitable for titanium, since so many improvements and refinements in technique have been made. α-β alloys are generally not ductile-weldable. Ti-6Al-4V is superior in this respect but requires a bend radius of at least 12T. Fusion welding is best for Ti-1Al-16V, and excellent weld properties are obtained for Ti-5Al-2.5S by arc, spot, seam or resistance butt welding. The limited weldability of Ti-4Al-3Mo-1V is extended by decreasing the aluminum, increasing the vanadium and replacing the molybdenum with chromium. B-120VCA is ductile-weldable in the solution-treated and annealed condition if shielding is good. Details of the different techniques are described and photographically illustrated.

68. New welding methods join exotic metals.

CHEMICAL ENGINEERING v. 66, n. 21, p. 222, 224, 226, 19 Oct 1959.

Among the new welding techniques applicable to titanium, zirconium and molybdenum are high-frequency welding, electron-beam welding and welding with ultrasonic vibrations. The application of high-frequency current causes localized heat at the weld surfaces, which may be joined with the aid of mechanical pressure. The process permits unusual shapes and is suited to automatic control. There is little weld flash. Electron-beam fusion welding avoids weld contamination by obviating electrodes and inert atmosphere. Welding with ultrasonic vibrations has the advantages of avoiding applied heat and contamination through arc, spark or smoke. Surface preparation is not critical. Makers of commercial equipment are noted.

69. SEAMLESS AND WELDED UNALLOYED

TITANIUM WELDING FITTINGS.

American Society for Testing Materials,

Specification B363-61T dated 3 Dec 1959,

These specifications cover wrought welding fittings intended for general corrosion-resisting and elevated-temperature services, factory made from three grades of unalloyed titanium. The therm "welding fittings" applies to butt welding (seamless or welded) parts such as 45° and 90° elbows, 180° returns, caps, toes, reducers, lap joint sub ends and other types as covered by the American Standard for Steel Butt-Welding Fittings (ASA No. B16. 9), and the Standard Practice for Light Weight Stainless Steel Butt-Welding Fittings (SP-43) of the Manufacturers' Standardization Society of the Valve and Fittings Industry.

These specifications do not apply to cast welding fittings.

70. Welding metals: Titanium

WELDING DESIGN AND FABRICATION

DATA BOOK, 1960 – 1961 p. D75 – D79.

Consumable electrode, gas-shielded welding, resistance welding or the Tig process produce good welds in titanium. Spot welding or flash butt welding also produce good welds, ubt the oxyacetylene, atomic hydrogen and coated electrode methods do not. Jigs and fixtures must assure rigidity and a flow of helium against heated parts and in the trail of the moving arc. Helium allows greater speed but argon gives greater arc stability. Welding of alloys is governed by the presence of β phase. $\alpha + \beta$ with less than 3% β stabilizers are weldable but require heat treatment. Colors given to welds by different atmospheric contaminants permit visual inspection. Lap- or butt-joints of titanium may be formed by the torch, twin carbon arc, furnace, induction and resistance methods of brazing. Heating times and temperatures should be minimized and silver fillers are recommended. Soldering has been accomplished in helium using silver, copper and tin chlorides, silver/silver chloride, and tin-lead alloy. Heating by acetylene torch is preferred. An appended section presents diagrams of typical joint designs for welding titanium. Data are tabulated.

71. Welded titanium tubing curbs corrosive attack of acids. IRON AGE v. 187, n. 2, p. 68-69, 12 Jan 1961.

National Lead Co. is using a number of titanium heat exchangers produced by Saffran Engineering Co., St. Clair, Mich. Fabrication involves use of a modified Heliarc welding gun for joining legs, spacers and risers to coils. Trailing shields are unnecessary. The problem of supplying backup protection to the underside of the weld joining long lengths of tubing is solved by attaching a bronze diffuser to a section of small diameter steel pipe, stopping seepage of argon with a series of gaskets behind the diffuser, and fitting a bronze gasket into the opposite end of the tubing to serve as a gas bleeder. A cannister is jigged around the sections to be welded. Photographs are shown.

72. Improvements in the welding procedures of metals, particularly of titanium. Establissements Jacques Lefebvre et Cie. French Patent 1,259,049. Abstracted in: BREVETS D'INVENTION v. 2, n. 13, p. 2996, 31 Mar 1961. (In French)

Before a titanium bar is joined to a bar of steel, brass, etc., the titanium is covered by a protective layer, e.g. of copper. This layer is obtained by coating, electrolysis, etc. The welding is then carried out in a sleeve into which the weld metal is inserted.

73. Welding titanium. TOOL AND MANUFACTURING ENGINEER v. 47, n. 3, p. 115-116, Sep 1961.

General considerations presented on welding titanium include protection again embrittling contaminants, applicability of Tig and SIGMA types of fusion welding, use of filler wire, and joint design and fit-up. Welding data are tabulated for the square butt, single V, double V, single U, double U, and fillet designs.

74. Welding thick light metal plate. LIGHT METAL AGE v. 19, n. 9/10, p. 7-8, Oct 1961.

A section on Batelle developments in welding 2-in thick titanium plate notes the possibility of application to submarine hull structures. Weld joints were a double-V design. All welding was performed in an argon-filled chamber with an automatically controlled

74. (cont'd)

comsumable-electrode process. Ti-6Al-4V plates and Ti-5Al-2Nb-1Ta filler wire give the best combination of yield and impact strengths, but improvements may be possible through the use of better alloys.

75. Wilford, C.F. and Tylecote, R.F.

Hot pressure welding of titanium. BRITISH WELDING JOURNAL v. 7, n. 12, p. 708-712, Dec 1960.

Values of minimum deformation and pressure needed to effect welding of commercial titanium were obtained for the 25° – 900° C range. A deformation of 57% is required to weld at 25° C, or a pressure of 100 tsi. As the temperature rises above 500° C, the minimum deformation becomes small, and a pressure sufficient to avoid gas pickup is adequate at 700° C. Titanium bar was pressure butt welded in the 500°–900° C range and tensile tested. Greater sensitivity of notched-bar impact tests to weld interface properties is noted. Post-heating welds for 30 min at 950° C give better ductility and impact strength. Tables, graphs and micrographs are shown.

76. Wilson, J.W.

FEASIBILITY STUDY OF PLASMA WELDING OF REFRACTORY METALS. Stanford Research Institute. Progress Report 3, 22 Mar 1960, 4p. (Contract NOas-59-6234C) OTS PB-148 425.

The feasibility of welding molybdenum, titanium, and zirconium by use of the plasma jet is under study. Construction and operation of a small plasma torch are being investigated. Possible advantages are smaller heat-affected zones, high welding speeds, and less contamination.